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Too Early or Too Late for CCS - What Needs to be Done to Overcome the Valley of Death for Carbon Capture and Storage in Europe?

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Abstract

Climate change has been identified as a key challenge for our modern society. Economic growth and societal welfare has always been associated with increasing energy consumption and environmental pollution. However, the key question to be answered is how much of our money we would like to invest in a better environment. The most cost-effective solution to combat climate change would be to reduce the emission of greenhouse gases where this could be done at lowest cost. However there is no real driver to reduce emissions for an individual, unless there is a legal requirement or a cost associated to the release of CO_2. Neither option will work if it is applied only at national or regional scale. At a European and Member State level, numerous policies are in place designed to incentivise carbon reductions to facilitate the introduction of low carbon technologies such as Carbon Capture and Storage (CCS). In Europe, the financial support for CCS demonstration via the EEPR and the NER-300 initiatives gave an expectation of the construction of 10-12 demonstration plants in Europe. The hope that these projects can be successfully deployed has been significantly declining in line with falling CO_2 certificate prices. Near term stalling of CCS deployment in Europe, including technology readiness (e.g. up-scaling, by-products, emissions, aquifer storage); economics (CAPEX, OPEX), liabilities (e.g. probability, value, guarantees); and public and political acceptance is a likely future development. Different support mechanisms need to be applied for technology development, technology introduction and technology deployment, taking into account local conditions and interactions between different instruments. In particular all measures for technology deployment should enable a level playing field for CCS and other carbon reduction options.

Keywords: CCS; Demoprojects; EEPR; Innovation; Barriers; Opportunities; ROAD; Public Acceptance

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1. Introduction

Climate change has become a widely accepted challenge for the future growth and welfare on our mother earth. Since the first IPCC Assessment report in 1990 [1], climate change has become apparent and the clear necessity for action has been pinpointed. Increasing greenhouse gas emissions from human activities, ranging from power generation through industrial processes such as cement and steel production as well as impacts from deforestation and clearance by fire have been translated to a significant increase of the concentration of green house gases in the atmosphere. **Fig 1**.shows development of the atmospheric CO_2 concentration measured at the Maua Loa Observatory, showing a clear and continuing increase of atmospheric CO_2 concentration since the beginning of the measurements

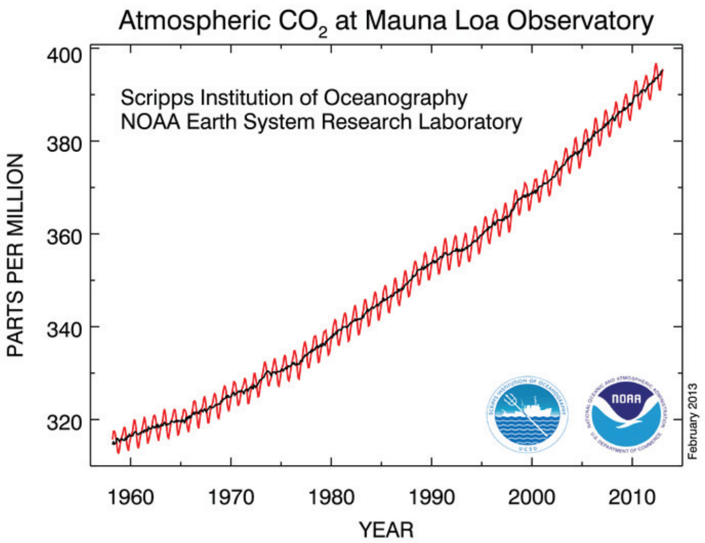

Fig. 1. Atmospheric CO_2 concentrations at Mauna Loa

1.1. Measurers to reduce greenhouse gas emissions

There are a number of different possibilities to reduce greenhouse gas emissions in the future, the most obvious being energy efficiency and increased used of renewable energies, cf. **Fig. 2**. However none of the possible technology options to reduce emissions can be seen as a silver bullet and a broad mix of measures will be necessary to achieve the required reductions. All types of measures will come with individual potentials, costs and possible speed of implementation, so careful analyses and understanding of possible repercussions and interdependence have to be taken into account.

Politicians worldwide are trying to address these challenges by defining appropriate energy policies, at regional or national scale. These range from market driven approaches such as the European Emissions Trading System ETS, incentives-driven options such as feed in tariffs, direct taxation of CO_2 emissions or approaches driven by the development of standards. Most countries are trying to develop a mix of different policies to achieve the energy policy targets; taking into account that one instrument implemented will require additional measures at a later time

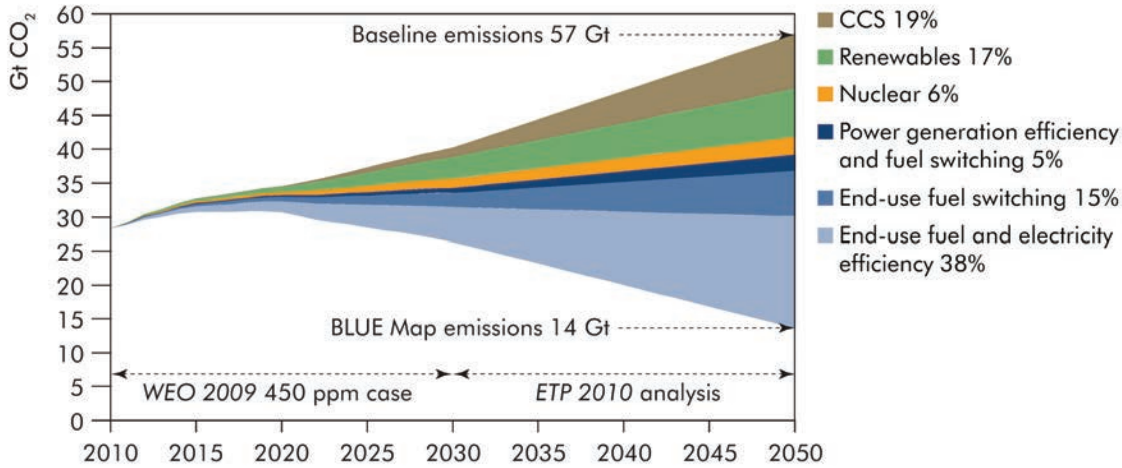

Fig. 2. IEA Blue Map Scenario to reach 2050 Emission reduction targets [2]

1.2. The role of CCS for climate change mitigation

As can be seen from the 'blue-map' scenario of the IEA in **Fig. 2**, CCS is expected to contribute an overall of 21% of the required emission reduction by 2050, with half of it to be realized in industry and the other half in the power sector. Calculations made by the IEA showed that in scenarios without CCS, the total cost to halve CO_2 emissions levels by 2050 would increase by 70%. Therefore, the successful implementation of CCS in the future will be key to ensure an affordable energy supply by achieving the challenging emission reduction targets at minimal cost. It is clear that affordable energy is not simply a target in itself but instead it will guarantee economic growth and welfare for the world's increasing population.

However, CCS is an innovation to decarbonise fossil power generation in an early phase of development with, currently, a significant number of pilot plants up and running to test the technology in the power sector. So a key question is from which point in time the technology is needed and what does this mean for the required development path? Given the scenarios of the IEA, CCS must be fully deployed in 2050 and therefore people might tend to the conclusion that CCS is too early for the market as it is neither required nor adequately rewarded at the moment. The next section therefore looks at the challenges and opportunities to enable CCS to play a role in our future energy system

2. Challenges and Opportunities for CCS Demo projects

During the last 10 years, CCS pilot plants have been set up and operated to gain the necessary insight into the technology and its challenges. This is reflected in a significantly increasing number of scientific journal papers and a broad range of conferences related to the topic with an increasing number of participants during this time. In 2009, when Europe encountered economic difficulties, the EU Commission started the European Economic Program for Recovery (EEPR), offering a total of more than 1 Billion Euros for 6 CCS Demo projects to be developed after the implementation of the EU Directive on the Geological Storage of Carbon Dioxide [3]. In the following sections, different aspects of importance to driving forward demonstration projects are discussed.

2.1. Regulation

The EU CCS Directive provided the legal framework for the storage of CO_2 in the EU. However, to be applicable in the different Member States (MS), the EU directive needs to be transposed into national law. Member States have 2 years for this realization but only Spain transposed the directive in the required time, and the Commission started infringement procedures to the MS not having transposed the directive. By the beginning of 2012, fortunately most MS with demonstration projects under way had implemented the CCS directive. However, due to the delays in transposition in Germany, the Jänschwalde demonstration project was cancelled at the end of 2011.

From the 6 EEPR projects, only the draft storage permit of the ROAD project in the Netherlands has been submitted to the EU for comment, and this was finally evaluated positively by the Commission on 28 February, 2012. No other storage permit has been submitted for review to the Commission, showing the difficulties and delays with storage sites. The legal status report of the IEA [4] analyses in more detail the different challenges world-wide, including the OSPAR and London Convention which have been amended for CCS but with the amendment not yet ratified.

Project developers are facing, in addition, the challenge that there remain significant uncertainties regarding the liabilities and the handover processes and requirements after the CO_2 storage phase has been completed. A critical issue with the liabilities is linkage to the ETS Directive, so that for every tonne of CO_2 which might leak an emission certificate has to be surrendered. Whereas the technical risk of the tonnage of CO_2 which might leak out can be quantified, it is much more difficult to quantify the certificate price at the moment the CO_2 might leak, which can be in 30 or 50 years time as this price is determined politically by climate policy in Europe.

It should also be noted, that –as it stands now - capturing and storing CO_2 from biomass-fuelled CCS will not lead to any benefit from the ETS, as biomass installations are currently treated as CO_2 neutral and therefore have no advantage under the legislation if they reduce avoid their CO_2 emissions through capture and storage.

2.2. Economics and Financing

As with most environmental technologies, cleaning up power plants or industrial installations by CCS will require additional investments for equipment and will increase the operational costs of the plants. There have been a number of studies undertaken trying to quantify these costs and their impact on the power price [5]. For commercial deployment of CCS, these costs need to be recovered from the market to make it attractive for investors to apply CCS. At the beginning of a learning curve, introduction of new technologies needs financial support from public sources as the additional costs and risks cannot be recovered from the market. Therefore support schemes such as the European EEPR program and the NER-300 support for CCS demonstration projects are necessary but not sufficient to make the project work. Additional national support by capital grants and/or feed in tariffs will most likely be necessary to bring demo projects to a positive investment decision. The cost for adding CCS at demonstration plant scale of 250 MW_{el} will typically be in the range of 500-1000 Million Euros, with EEPR and NER-300 providing a maximum funding of 180 and 337.5 million Euros limited to 50 % of the total costs, respectively. In times of economic recession with a reduced need for power, investment in new power generation capacity is typically delayed and the willingness to invest in loss making projects with an uncertain future is hugely reduced. So additional support from MS, by tariff incentives or other additional revenue streams such as the sale of CO_2 for Enhanced Oil Recovery (EOR) are necessary to make projects happen.

When the CCS demonstration projects started planning in 2008, companies (and indeed, legislators and regulators) were expecting a further rise of certificate prices in the near future, giving a sound optimism that the savings in CO2 certificates will be able to compensate for the additional costs of CCS after the demonstration phase, therefore opening a business perspective for the technology. Certificate prices of 25 Euros per tonne of CO_2 had been a common assumption and went into the economic calculations of the project proponents. As can be seen in **Fig. 3**, the certificate prices have, however, declined since then and now languish at a price of around 7.5 Euros per tonne. Since, for a 250 MW CCS facility, the total emission to be captured is around 1 Million Tons of CO_2 per year, the drop in the certificate price produces an additional financial gap of about 20 Million Euros per year for the operator. At a price level of 7.5 Euro per certificate, the operational costs of the CCS chain is more expensive than the potential savings, so each hour of additional operation will lead to additional losses.

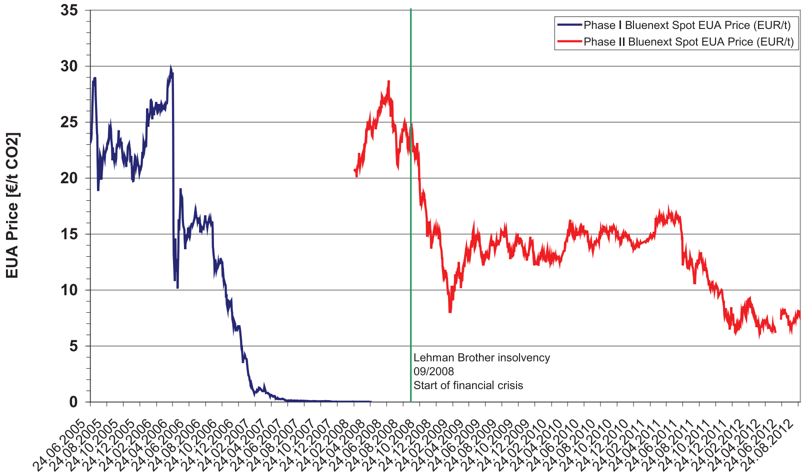

Fig. 3. CO_2 Spot price over time

It should be noted that all demo projects in Europe are faced by the same economic challenges. The Zero Emission Platform has therefore developed a report on what could be done to improve this situation [6]. Without additional European or National support, the demanding CCS demo program of the EU, having 8-12 demo projects running in 2015, will fail. In the worst case, no CCS demo project might be realized. This would most likely harm the further development of CCS in Europe for a long time.

2.3. Public Support

Different technologies to mitigate climate change are perceived quite differently by the general public. With renewable energies having the highest support rate in general, even if public opposition against wind farms onshore or the public debate on biomass derived fuels also show increasing difficulties for them. In western societies, all large scale infrastructure projects from motorways, airports and pipelines to train stations or train lines are heavily debated. A key challenge with all infrastructure projects is the fact, that advantages and disadvantages for any individual need to be balanced with the advantages and disadvantages for the society. Carbon capture and storage as a new technology has still to explain and to prove its merits to the public, requiring the testing and application of the technology at demo scale.

CCS can easily be attacked as green-washing for fossil fuels or by raising fears about the explosiveness of the gas (a wrong but often made statement) or by linking disastrous natural releases of CO_2 to technical storage. The difficulty lies with the challenge of proving general statements where it is, for example, easily said that a storage site could leak but difficult to prove a 100% leak free site upfront. As with all types of technologies, there is always a remaining risk for each technology, however this can and should be brought close to zero.

All this has caused severe delays for demo projects planning to store CO_2 onshore. E.g. gaining public support for onshore storage in Germany was impossible, leading to a stop of the Hürth IGCC project with CCS. So a first logical step might be to start with CO_2 storage offshore to further prove the safety of storage. It is worth noting that, to date, the running demo projects related to oil and gas production such as the Sleipner project have already stored more than 10 Million tonnes of CO_2. Whereas people do not object too much to the capture part of the chain, the transport infrastructure and CO_2 storage are questioned in many parts of Europe. There is still a strong belief in the general public, also supported by a number of politicians, that the electricity supply can be shifted completely to fluctuating renewable energies and therefore CCS might not be necessary. However people tend to ignore the fact that electricity from renewables together with the necessary reinforced grids and energy storage will be more costly than allowing CCS in the electricity mix. Looking on the first order effects, the additional costs for a single household seem to be affordable, but often the second order effect is overlooked. European industry has to compete internationally and significantly higher electricity prices will reduce the competitiveness of the industry, which is the key driver for economic growth and jobs in Europe. Therefore job loss in Europe due to high electricity prices will play a much more important role than the individual increase of the electricity bill per household.

So far, regulatory focus has largely been on emission reduction from power generation. However CCS is has a much broader application than the power sector alone. Industrial process emissions (e.g. steel, cement, lime, and fertilizer) cannot be displaced by switching to a supply of renewable energy; they will still emit a significant amount of CO_2. Industry has been reluctant so far to address CCS to a larger extent as long as the application of CCS is not rewarded by the market, but it will most likely be key to getting a broader support for CCS in Europe.

2.4. Technology

Improvement of the technology is necessary to bring down the capital and operational costs for CCS. Since the early developments, significant progress has already been made, bringing down the energy penalty from 17%-point to values of around 8%-points. It is expected that significant further learning effects can be realized, based on the experience from demo projects and further R&D [7]. However better understanding of the technology based on a significant number of pilot plants in operation and research done at universities, it is also clear that new issues have been appearing, such as the emissions of solvents and degradation products with the decarbonised flue gas. Technological challenges typically trigger new solutions. Compared to barriers from regulation, economics and public acceptance, technological barriers can be addressed and solved by technology providers or technology adopters, whereas the others require the engagement of a much broader number of stakeholders with diverse interests, making the resolution much more complex and time consuming.

3. The Innovation Cycle applied for CCS

The concept of Innovation Cycles is aimed at understanding the different phases an invention has to go through before it can be declared as a success, cf. **Fig. 4**. This concept can be applied to all types of inventions and is not limited to CCS. In 2007 a study [8] tried to systematically understand the process and possible indicators for the different innovation phases. The most critical point in the process is between phases 3 and 4, when disillusionment triggered by lower expectations or challenges larger than expected are encountered and the new orientation has not yet been successfully leading to a new rise of activities and prospects.

It should be noted that the disillusionment is not only due to new issues with the technology development, e.g. possible solvent emissions from post combustion plants, but to a much stronger reason linked to the business perspectives of the technology. As CCS is actually predominantly linked to fossil power generation a darkening perspective for new power projects in Europe due to economic recession and significantly rising renewable capacities reduces also the prospects for CCS.

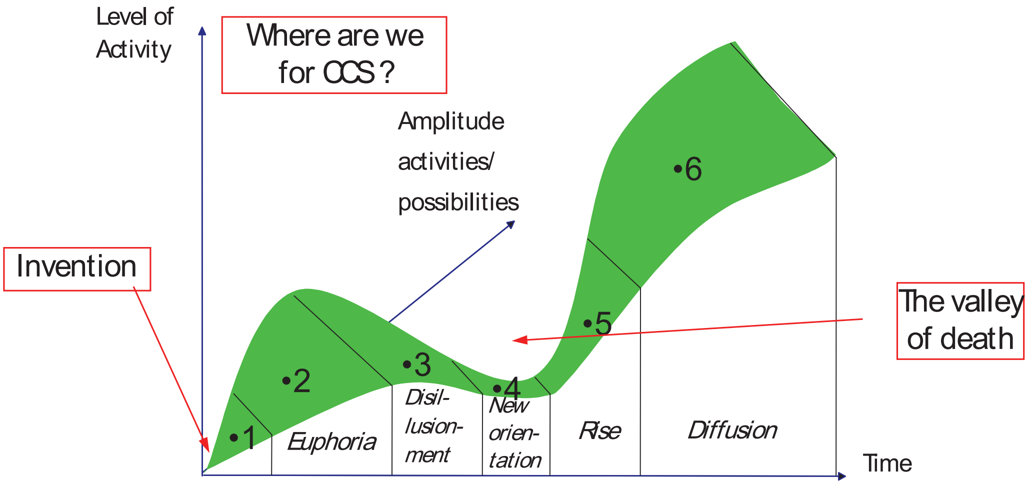

Fig. 4. Model of the innovation cycle

The question if it is too early or too late for CCS cannot easily be answered. Most actors in CCS still believe that CCS is a necessary technology to combat climate change and to enable the achievement of the emission reduction targets until 2050. A new orientation for CCS can be to move to new options such as capturing CO_2 emissions from industrial plants first or by using the CO_2 for enhanced oil recovery (EOR) applications or as feed stock for other industrial products such as plastics (polycarbonates).

It is important to keep a minimum level of activities to prepare for the future rise, as it takes normally a number of years to build up capacities in development, engineering, procurement, manufacturing and operation of such large scale systems.

The European Commission introduced its EEPR and NER-300 support programs when the technology was in innovation phase 2 and this has led to a significant increase of activities to develop and deploy CCS. At this time, some stakeholders felt that the technology was already in phase 5, ready for the start for large scale deployment, even if a number of actors had warned that the program should be less ambitious and optimal plant sizes for the demonstration program should better be 100 MW_{el} than 250 MW_{el}, which would have reduced significantly the investment and operational cost of the plants without reducing the potential learning. It could be argued that it was too early for CCS to enter in the deployment phase of the technology. If the technology can make a turnaround to bridge the 'valley of death' this could lead to a resurgence in a number of years. Otherwise the technology might disappear from further discussions.

4. From Project Studies to Project Implementation

Looking at the current status of demo projects can therefore help to identify what needs to be done on the short and medium term to overcome the actual challenges. For the further development of CCS it will be crucial to bring at least some demo projects to financial close and hence engineering reality to enable a relevant level of activities to be held at utilities, suppliers and governments. Urgent action is needed to bundle forces to achieve and retain the necessary minimum critical mass to stay prepared for the future.

4.1. The status of EEPR Demo projects in Europe

The European Commission made funding available for 6 demo projects in Europe at the end of 2009, aiming at having the demo projects in operation in 2015 at the latest. Towards the end of 2011 one of the six demo project was terminated by the owner, who saw no chance of bringing the project to financial close. It appears, from the information available to the authors of this paper, that the 5 other projects are all challenged, albeit to differing extents. Certainly none of them have reached the final decision point of financial closure and taken a financial investment decision. **Table 1** gives the authors' perceived overview on the advancement of the projects based on different criteria. As can be seen from our evaluation, we expect only 2 projects to have a chance of achieving a financial investment decision in the near term and only the ROAD project appears ready to take a financial investment decision if financial close can be achieved. As projects can typically not remain idle for an indefinite time, there is, in addition, a severe risk that projects which are ready for financial investment decision but cannot be brought to financial close will be cancelled, even if all other conditions would be ready for the decision.

If Europe wants to get forward with at least one or two demo projects, then immediate action will be necessary to enable the ROAD and the Don Valley projects to close the open gaps. Financial closure will be the most challenging one, as economics of projects have been seriously worsened due to the weak CO_2 certificate price. Shifting or reallocating the unspent money from the cancelled demonstration projects to the promising ones could be an important step to make this happen. However, to make this possible, a broad coalition of European Commission, European Parliament, MS and industrial companies would be necessary but this seems to be difficult or even unlikely. The Don Valley and ROAD projects have indicated their openness for additional partners and all interested partners could play a role, however in the past there seemed to be no interest of other oil, gas or power companies to share the expected substantial loss against substantial learning's and to make these projects happen to drive CCS development in Europe. Acknowledging the recent changes for other demo projects and the overall framework, the Don Valley and ROAD project have restarted to look for additional partners being willing to team up.

Table 1. Readiness for final investment decision of the EEPR projects (own analysis)

Name of Demo project	Permits Capture and Power Plant in Place	Implementation CCS Directive in national law	Permit Storage in place or can be obtained within the next 12 month	FEED for Capture Plant Completed	Public Support for Project	Financial close completed
Don Valley (UK)	◕	●	◕	●	●	◑
Belchatow (PL)	◕	◕	○	●	◑	◔
ROAD (NL)	●	●	●	●	●	◕
Compostilla (ES)	○	●	○	◑	◕	◔
Porto Tolle (IT)	○	◕	○	●	◑	◔
Jänschwalde (DE)	Project was cancelled by project owner at the end of 2011. The CCS Directive was not implemented in Germany at this point in time					

4.2. The status of NER-300 Projects in Europe

The hope for a second wave of CCS demo projects triggered by the NER-300 funding mechanism is now also reaching the finalization of its first round of call for proposals with award decisions by the Commission expected before the end of 2012. At the end of last year the ZEP Task Force Demo and Implementation undertook an anonymous survey across the demonstration projects in Europe [9]. 13 out of 14 European demonstration projects participated in the survey. **Fig.5** shows the results of the survey regarding the share of funding which is required, based on the assumption of the project managers. About 80% of them believe that a funding ratio about 50 % will be required for FID.

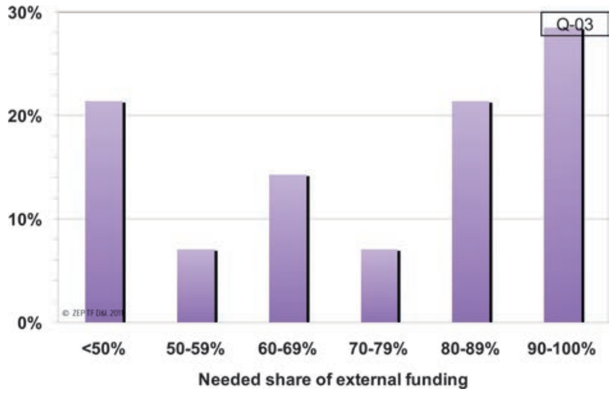

Fig. 5: How much funding is necessary for FID [ZEP, 2011]

Asked what they would see as the key challenges for their projects to achieve FID, most managers pointed to the current ETS price level, the negative NPV of the projects and the storage site qualification, cf. **Fig. 6**.

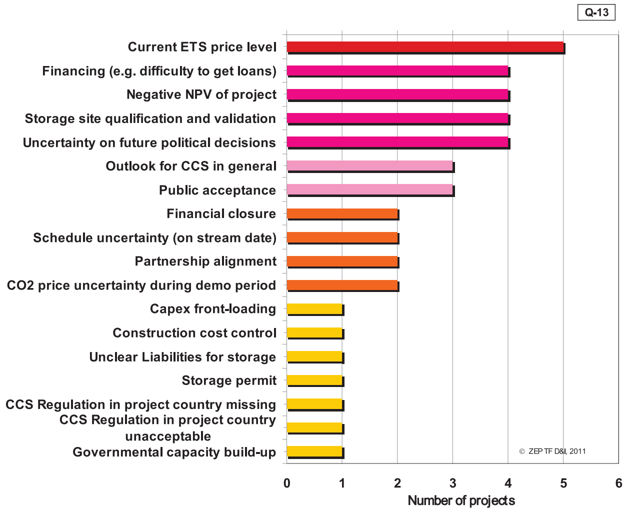

Fig. 6: Key challenges for FID [ZEP, 2011]

In July, the EC published the results of the due diligence [10] of the applicant projects and is waiting for confirmation of co-funding for the projects by the MS until middle of October 2012. As can be seen from the ranking list (**Table 2**), the two highest ranked projects on this list have already received EEPR funding, but especially the Belchatow project might not be able to fulfill the required start up date of the plant four years after the NER award decision, as the onshore storage site appears unlikely to be ready in time.

Table 2. Readiness for FID of the NER-300 projects ([10], own additions)

Project Name	Project Promotor	Ranking Positions	Received EEPR funding
Don Valley (UK)	2CO	1	Yes
Belchatow (PL)	PGE	2	Yes
Green Hydrogen (NL)	Air Liquide	3	
Teeside CCS (UK)	Progressive Energy	4	
UK Oxy CCS (UK)	Alstom, Drax Power, National Grid	5	
C.GEN North Killingholme (UK)	C.Gen	6	
Porto Tolle (IT)	ENEL	7	Yes
Ulcos BF, Florange (FR)	Arcelor	8	
Getica (RO)	CE Turceni, Transgaz, Romgaz	9	
Peterhead (UK)	Shell	10	

The Green Hydrogen project in Rotterdam harbor close to the ROAD project is planning to jointly use infrastructure with the ROAD project; a failed FID for ROAD would therefore also impact the Green Hydrogen project which could in this case most likely be cancelled as well. As the funding available for CCS under the NER-300 program will be most likely between 750 and 900 Million Euro and a maximum funding per project of 337.5 Million Euro, only two power and one industry project (with lower funding requirement due to lower total amount of capture) can be awarded based on available funds. Just recently, Arcelor Mittal announced the definite closure of steel production at its Florange site [11]. Therefore the only candidate for capture from industry in the NER-300 competition remains the Green Hydrogen project.

As a larger number of projects on the NER-300 candidate lists are UK based, it will be important which projects will get the backing of the UK Government. The key challenge for the UK is that they have to align their 1000 Million GBP demo project funding with the process at EU level. However the EU and the UK are using different evaluation criteria for the projects. The EU is using the cost per tonne of CO_2 as their benchmark, whereas the UK is using the cost per clean Megawatt-hour. Whereas the first give gas projects such as the Peterhead project no realistic chance compared to coal fired plants, they can compete well on the clean Megawatt-hour. .A *modus operandi* is required by which the two parties can reach a common, or at least mutually acceptable, basis of assessment in order to maximize the likelihood and usefulness of the resultant demonstrations. .

4.3. The necessary steps to be taken

So, to summarize, the initial euphoria to have up to 12 CCS demo projects up and running in 2015 has not become reality, as delays for setting up the legal framework and providing the funding mechanisms, (albeit both of these were done quite quickly at the European level), has taken too much time. If both had already been in place in 2009, it is much more likely that project owners would have taken FID.

The end of 2012 will be a critical milestone for the future of the EU CCS demonstration program. When the award decision for the NER-300 had been taken and a possible way forward for a reallocation of remaining funds might have been identified, Europe still has the chance to see two to three demo projects taking FID. Clearly this will not be a surefire success but needs a quick and intelligent co-operation of the EU, MS and industry. Additional funding will be a key factor for overcoming the valley of death for CCS, as the prospects for CCS on the mid and long term are not assured in the currently climate policy framework. The recession in Europe together with a significant increase in renewable electricity production triggered by subsidies has undermined the Emission Trading System. Without a level playing field for all low carbon technologies it will be however difficult to achieve the solution at lowest cost.

Fig. 7 shows a highly simplified comparison of different electricity generation technologies. The calculation is based on a typical spot market price for electricity except for wind and PV, where the feed in tariffs in Germany are used. As can be seen, none of the fossil technologies, either with or without CCS, will be able to recover their full costs in the market, with combined cycle plants making less loss than open cycle plants due to higher efficiencies and coal plants performing better that gas plants due to lower fuel costs. Clearly plants which cannot recover their full costs on the market will not be built, however existing ones will be operated as long as revenues are higher than operating costs. The cost for electricity from PV and offshore wind is clearly more expensive than the fossil alternatives with or without CCS. Due to the high and secured revenue stream from the feed in tariffs, however these higher generating costs are more than overcompensated by the higher revenue streams.

It becomes therefore obvious, that it is not only the high costs for CCS but especially the revenue side which disadvantage fossil power generation compared to renewables and therefore weakening the mid term outlook for CCS unless additional mechanisms are identified to address the short-fall e.g. contract for differences allocated for 'de-carbonised' fossil power – a proposal under advanced discussion in the UK.

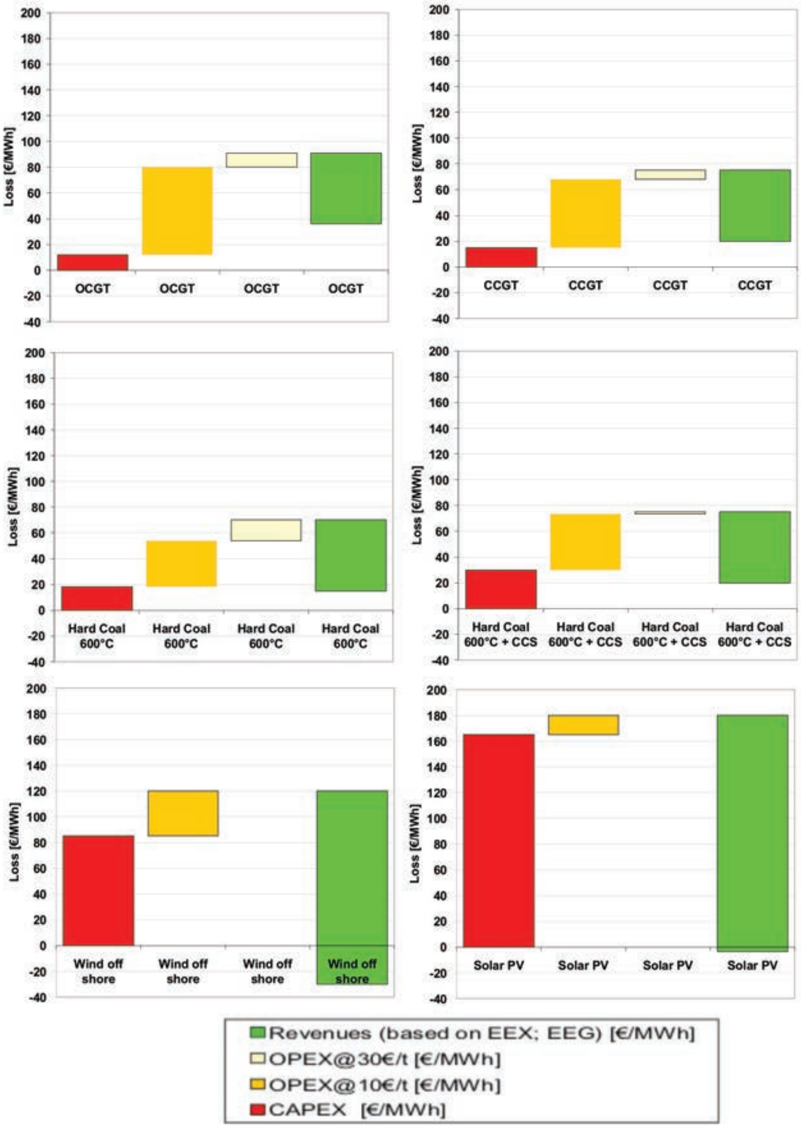

Fig. 7: (a) Economics of electricity generation technologies a) OCGT, b) CCGT, c) Coal, d) coal with CCS, e) Wind offshore; f) Solar PV.

5. Conclusions

When the EU and industry initially thought that CCS should be deployed it was, in reality, still too early for CCS, as neither the legal framework nor the technology nor the funding was in place to allow the technology to develop and rise into the electricity market. During the last five years, significant progress has been made in terms of all possible aspects, however the overall outlook has been darkened and the initial euphoria has receded.

Nevertheless careful analyses and joint progress is necessary to ensure, that reorientation will not come too late and that CCS technology will remain a possible and cost effective option to decarbonize our electricity system at low cost. All recent studies and roadmaps have proven the importance of CCS, even if not fully recognized by the general public. It is therefore important to ensure that CCS can keep its momentum to deliver from 2020 onwards. Therefore at least 2 or 3 demonstration projects have to be realized in Europe still during this decade.

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